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A WARM SEA BREEZE?

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ABSTRACT: On days when the marine air layer was shallow, a sea breeze front penetrated the central California coast in the early forenoon as a wind shear line. As the marine air moved inland it was rapidly modified and became nearly as warm as the air ahead of the front. The zone of temperature change remained nearly stationary a short distance inland from the coast, but the wind shear line continued to move inland nearly 100 miles. This phenomenon could affect forest fire behavior adversely.

The behavior of wildfires in the coastal mountains and valleys of California depends to a large extent upon the depth, penetration, and modification of cool, humid, marine air which develops over the upwelling coastal waters and moves inland during the summer and fall months with a monsoon circulation. Along the coast of central California the diurnal sea breeze circulation is superimposed on the monsoon circulation and is therefore a rather complex phenomenon.

One normally expects the sea breeze front to be followed by relatively cool, moist, marine air--as classical studies by Koshmeider (1935), Berson (1958), and Wallington (1959) have shown. Recent studies on the Pacific coast by Lowry,[1/] Schroeder (1961 [2/]), Staley (1957)

1/ Lowry, William P. The sea breeze of northwest Oregon and its influence on forestry operations. (Unpublished Ph.D. Diss. Oregon State University) 162 pp., illus., 1962.

2/ Schroeder, Mark J. A study of the penetration of marine air into the intermediate valleys of California. (Paper presented at 201st National Meeting of the American Meteor. Soc., Fairbanks, Alaska, June 26-29, 1962.)

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and Dickey[3], and in Australia by Reid (1957) and Clarke (1958) indicate that the sea breeze is much more complex than the classical studies suggest. The influence of terrain (Lowry[4]; Fosberg[5]) also complicates the structure of the sea breeze.

We now have evidence that when the marine layer is shallow, the sea breeze front can be followed inland as a discontinuity in the wind field, but the temperature discontinuity remains near the coast because of the rapid modification of the marine air.

Studies of the Sea Breeze

Two field studies were carried out north of San Francisco Bay to determine the structure, penetration, and modification of marine air as it moves into the coastal mountains and valleys: the first during a 46-day period in July and August 1961 to obtain the area picture, and the second during a 3-day period in August of 1962 primarily to obtain the vertical structure of the sea breeze.

On 11 of the days, the cool marine air penetrated less than 20 miles inland, though the sea breeze front, determined by the discontinuity in the wind field, penetrated nearly 100 miles. On these days, the sea breeze that reached the coastal mountains and valleys was relatively warm.

Seven of the eleven days on which a warm sea breeze was observed were selected for detailed analysis. A typical day, 15 August 1962, is presented in this note.

Structure and Penetration of the Sea Breeze Front

The sea breeze was studied through hourly wind and temperature cross sections to 5,000 feet through the Petaluma Gap and by hourly analysis of surface streamlines and sea level temperatures.[6] The survey network of stations is shown in figure 1.

The sea level temperature field at 0700 P.s.t. was nearly uniform over the survey area. The temperature cross section for 0700 P.s.t. revealed a deep inversion from summer nighttime cooling and subsiding warm air aloft. The wind fields at the surface and aloft showed only

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[3] Dickey, W. W. Anticipating cooling in eastern Washington and eastern Oregon in selected cases. (Paper presented at Western Fire Weather Meteorologists Conf. 1963)

[4] See footnote[1].

[5] Fosberg, Michael A. Sea breeze eddies of the Pacific coast. Manuscript report. U.S. Forest Serv. Pacific SW. Forest & Range Expt. Sta. Berkeley, Calif.

[6] Surface temperatures were reduced to sea level using the dry adiabatic lapse rate of 5.5°F per 1,000 feet.

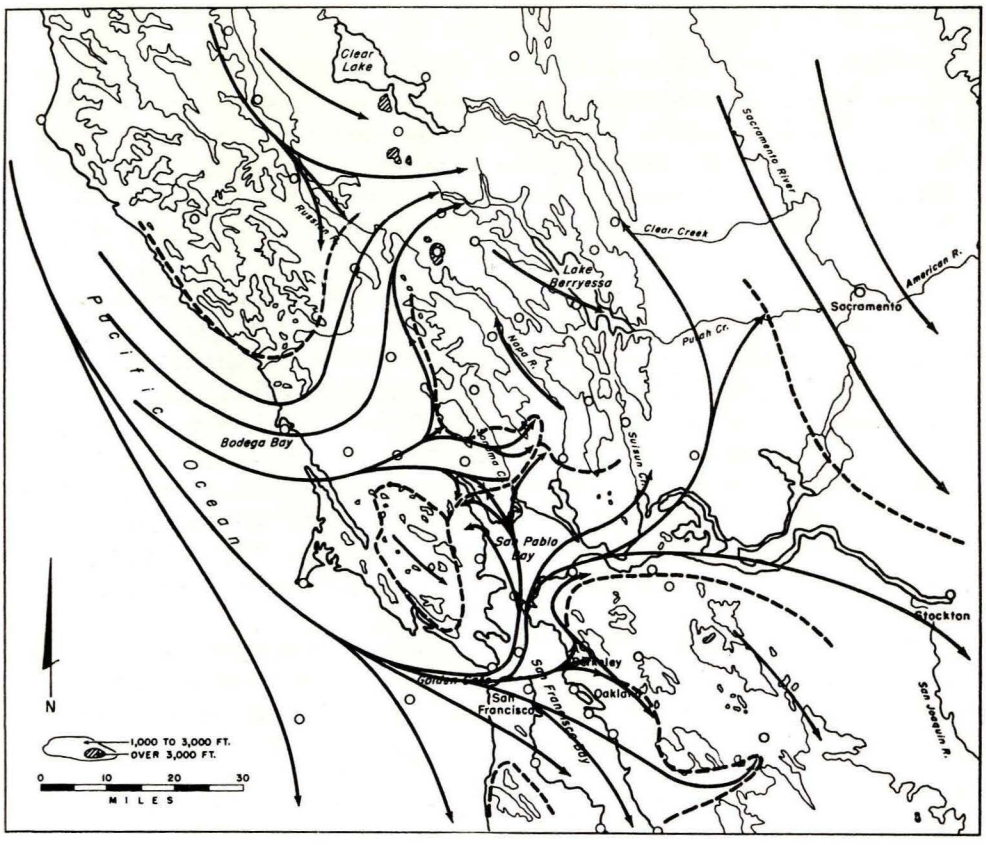

Figure 1.--Wind shift line (dashed) and streamlines for 1400 P.s.t. 15 August 1962. The network of stations on which the analyses were based is shown by small circles.

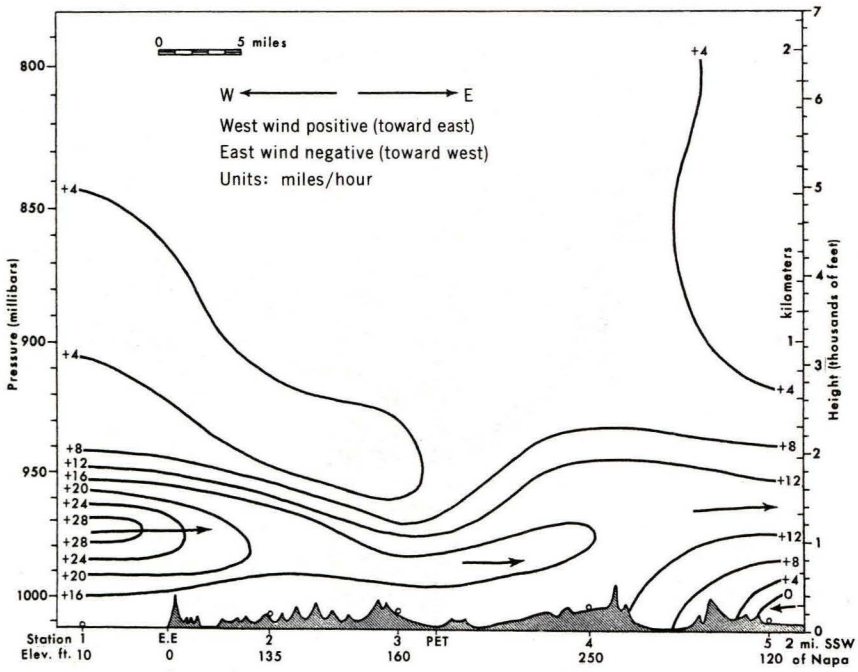

Figure 2.--Component of wind speed along the plane of a cross section from Bodega Bay to Napa for 1400 P.s.t. 15 August 1962. Units are miles per hour.

light, variable local circulations. Shortly before 0800 P.s.t. a strong, steady flow began to penetrate the coastline. The boundary between this marine flow and the light, variable winds ahead of it was characterized by a wind shift line at the surface (dashed line, fig. 1). Aloft the shear appeared as a discontinuity in the speed field, and between these two types of shear there was a broad transition zone (fig. 2).

As the marine air penetrated the coast behind the shear line, the inland air was warmed by surface heating, and a zone of temperature discontinuity formed. This zone, with marine air behind and warmer modified air ahead, moved inland with the shear line until about 1000 P.s.t. but then began to lag behind the shear line. Further modification was taking place, including warming of the marine air as it moved inland. By 1100 P.s.t. the temperature discontinuity ceased its forward movement. The shear line showed no sign of slowing as it moved inland but was warped about the topography (fig. 3). Packing of the isotherms (figs. 4 and 5) shows that the temperature discontinuity slopes back over the marine air.

Frontal zones generally imply a sharp temperature change between adjacent air masses, but Palmer (1957) has shown that kinematic discontinuities may also characterize fronts. From Palmer's work we propose that the wind shear line represents the sea breeze front and that it is

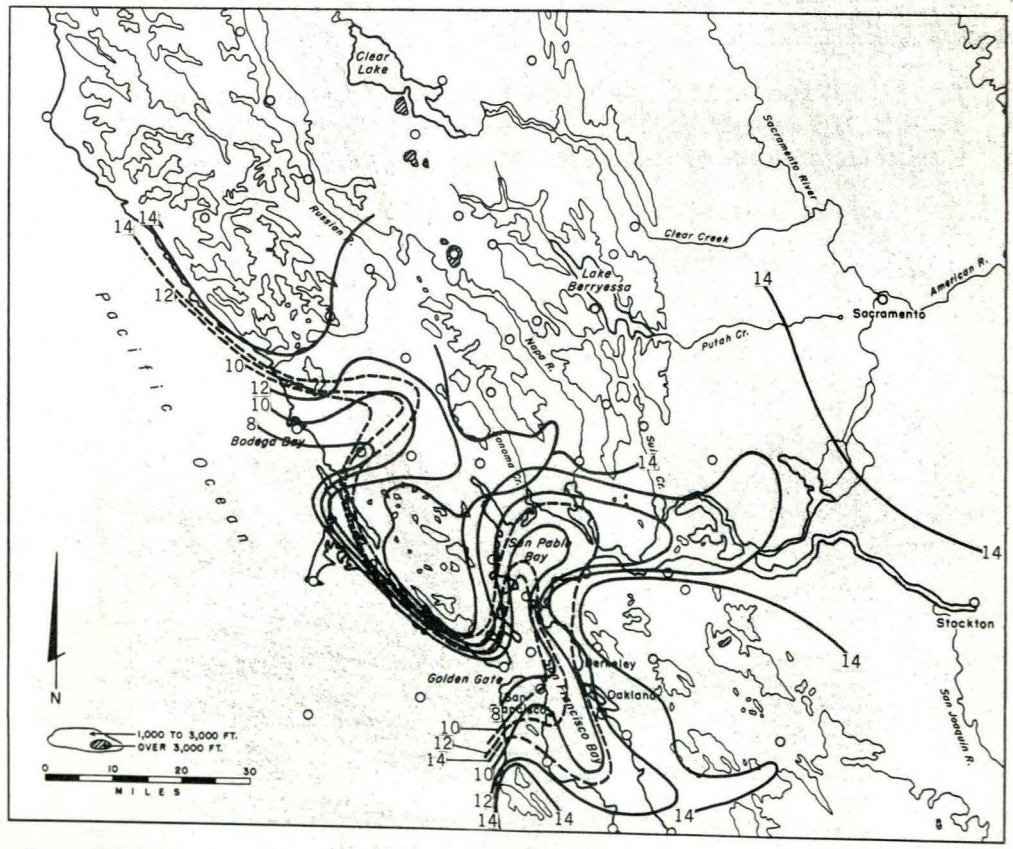

Figure 3.--Position of wind shift line (solid lines) and center of zone of temperature discontinuity (dashed lines) for specified hours 15 August 1962.

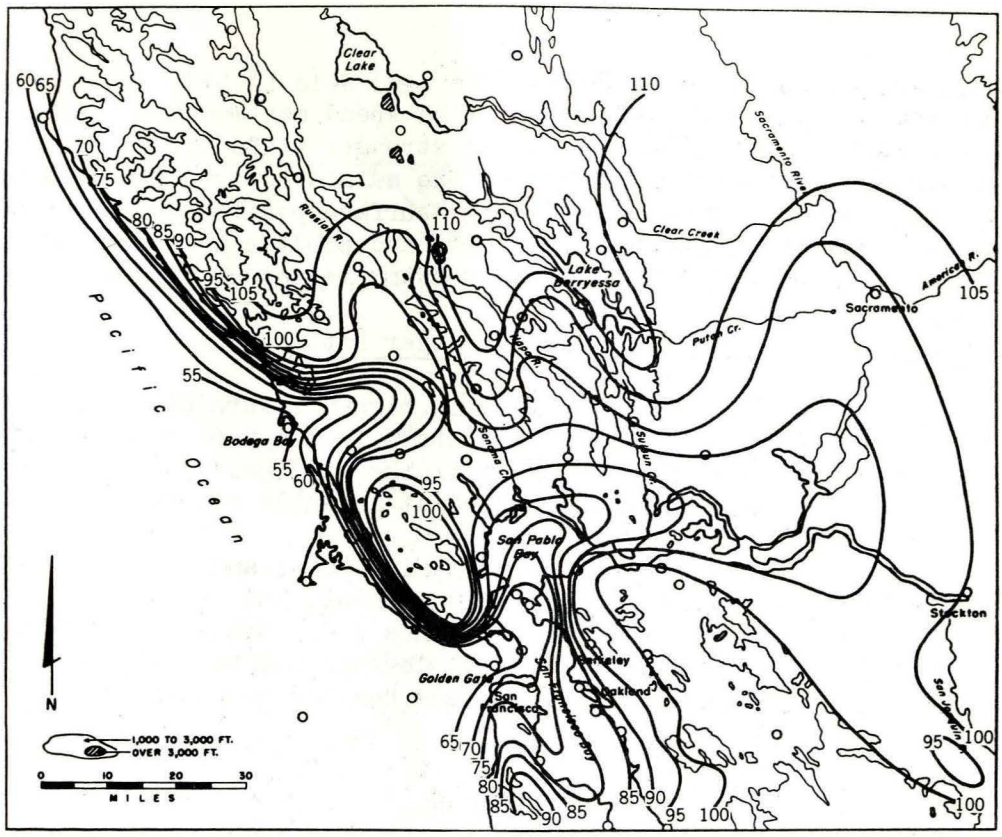

Figure 4.--Pattern of surface temperatures reduced to sea level (°F) for 1400 P.s.t. 15 August 1962.

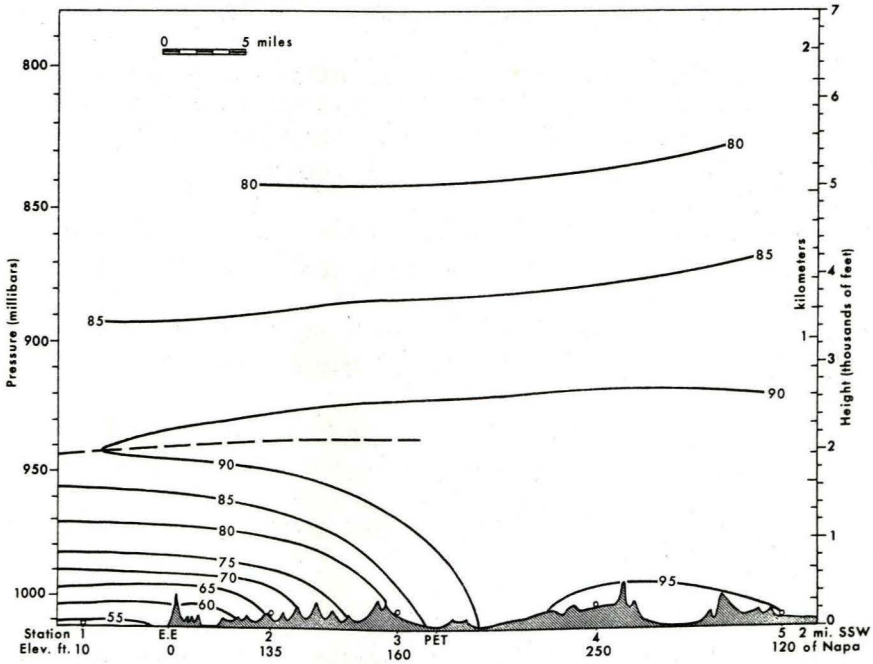

Figure 5.--Vertical temperature distribution (°F) along cross section from Bodega Bay to Napa for 1400 P.s.t. 15 August 1962.

the wind surge described by Schroeder[7] and Reid (1957). The wind shear line at the surface lags behind the wind speed maximum aloft (fig. 2). Further inland in the afternoon these stronger winds may well be brought to the surface through turbulence in the adiabatic or super-adiabatic layer. This mechanism could cause the surface position of the shear line to move rapidly, perhaps by jumps, and produce the wind range observed at inland stations such as Sacramento and Stockton.

The Large Scale Weather Pattern

On all 11 days the east Pacific high pressure cell penetrated into Oregon and Washington and the isobars in the survey area were oriented in such a way (fig. 6) that if the wind paralleled the isobars (i.e., was geostrophic), it would blow at an angle offshore.

Even though winds within the marine layer and over such short distances have a strong cross-isobar component, the geostrophic effect opposed a strong inflow of marine air in a deep layer. Consequently, the marine layer was shallow (somewhat less than 2,000 feet deep), and rapid modification by inland surface heating resulted in a relatively warm sea breeze.

Discussion

On days when the marine layer is shallow, the marine air that moves inland behind the sea breeze front is rapidly modified by surface heating. By the time the sea breeze air reaches the coastal mountains and valleys, it is nearly as warm as the air ahead of the sea breeze front, and the sea breeze front continues inland as a wind shift line.

Fire behavior may be adversely affected by passage of this warm sea breeze front. As it passes, the wind is likely to change in direction, increase in speed, or both. But the lower temperature and higher humidity usually associated with a sea breeze are not likely.

The time that the sea breeze front passes will, of course, depend upon the trajectory distance from the ocean, and even at any particular place the time will vary from day to day. On the days studied, the front crossed the coast about 0800 P.s.t. and progressed inland at an average speed of 10 m.p.h., but the rate of movement was by no means uniform.

Movement of the front is strongly influenced by topography. The front is retarded by terrain barriers, but moves unobstructed through low-level breaks in the terrain. As a result, the direction to which the wind shifts with passage of the sea breeze front will depend upon the local terrain.

It must be emphasized that the remarks in this paper are based upon the data for days on which the marine layer was shallow. Conditions

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[7] See footnote [2].

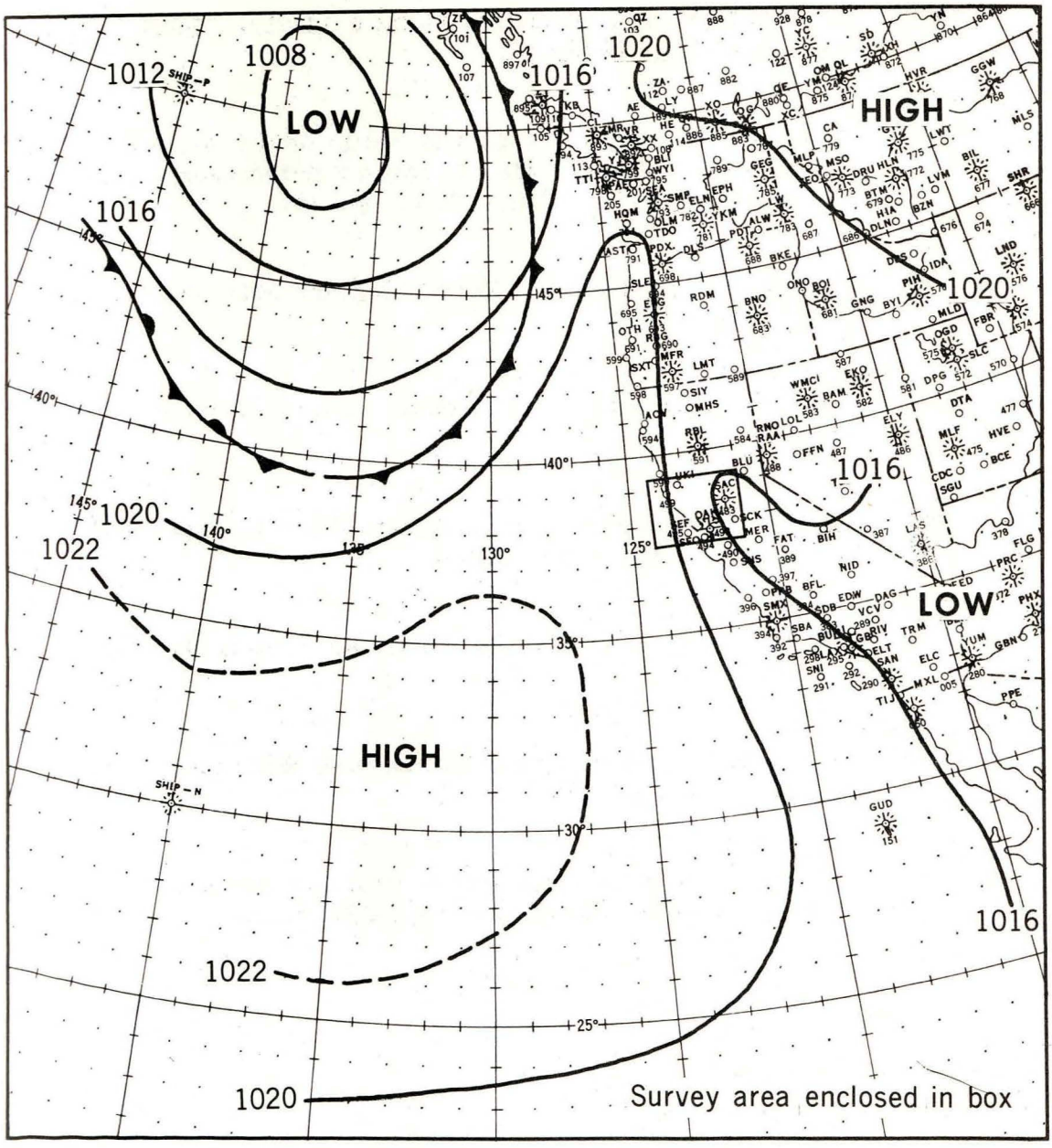

Figure 6.--Surface weather map for 1000 P.s.t. 15 August 1962.

will be different when the layer is deep, or when it is absent because of strong offshore pressure gradient. In the former case the marine air would be modified to a lesser extent as it progresses inland. In the latter case the sea breeze may be absent entirely.

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